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UH-2 JET-AUGMENTED HIGH-SPEED RESEARCH HELICOPTER MANEUVERABILITY AND DYNAMIC STABILITY EVALUATION

By

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July 1965

U. S. ARMY AVIATION MATERIEL LABORATORIES

FORT EUSTIS, VIRGINIA

CONTRACT DA 44-177-AMC-151(T)

KAMAN AIRCRAFT CORPORATION

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This report has been reviewed by the U. S. Army Transportation Research Command. The report is considered to be technically sound and is published for the exchange of information and exchange and stimulation of ideas. The program described is basically an extension of previous flight test work performed under Contract DA 44-177-AMC-105(T) and reported in USATRECOM Technical Report 65-14 dated March 1965.

The results presented further substantiate the higher performance potential of rotary-wing aircraft.

The Army is currently continuing to sponsor several high-speed programs of similar nature to provide basic technology for the future design of high-performance rotary-wing aircraft.

Current plans include provisions for similar flight testing of a configuration whose only basic change is that of an addition of a fixed wing.

NOTE

On 1 March 1965, *after this report had been prepared*, the name of this command was changed from U.S. Army Transportation Research Command to:

U.S. ARMY AVIATION MATERIEL LABORATORIES

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UH-2 JET-AUGMENTED HIGH-SPEED RESEARCH HELICOPTER MANEUVERABILITY AND DYNAMIC STABILITY EVALUATION

Kaman Aircraft Corporation Report No. R-553A

by
W. E. Blackburn
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Prepared by
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for
U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

ABSTRACT

The results of a flight research program conducted to determine the effect of horizontal thrust augmentation on the maneuverability and dynamic stability characteristics of the UH-2 high-speed jet-augmented research helicopter are presented. The research aircraft, instrumentation, and test program are described.

A standard Kaman UH-2 helicopter was modified by the addition of a General Electric YJ85 jet engine mounted on the right side of the fuselage for horizontal thrust augmentation. Transient and steady-state load factor maneuvers were examined at various airspeeds and levels of jet augmentation. The maneuver envelope is shown to be expanded by unloading the main rotor through the application of horizontal thrust augmentation.

The dynamic stability characteristics of the research vehicle are shown to be basically similar to the standard UH-2. The addition of thrust augmentation tends to increase damping in pitch and yaw and reduce control sensitivity.

PREFACE

This report summarizes the results of a flight test program conducted to investigate the effect of horizontal thrust augmentation on the maneuverability and dynamic stability characteristics of the UH-2 high-speed jet-augmented research helicopter. The program was conducted by Kaman Aircraft Corporation, Bloomfield, Connecticut, under Contract DA 44-177-AMC-151(T), with the U.S. Army Transportation Research Command (USATRECOM). Principal Kaman Aircraft Corporation personnel associated with the program were Messrs. A. D. Ashley, W. E. Blackburn, F. A. Foster, A. D. Rita, F. L. Smith, and A. A. Whitfield.

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SUMMARY

This report describes and presents the results of a flight research program to investigate the effect of horizontal thrust augmentation from an auxiliary jet engine on the maneuverability and dynamic stability of the UH-2 helicopter. The testing is an extension of the prior flight research program reported in Reference 2.

The effect of transient and steady-state load factors on the airspeed envelope, as limited by retreating blade stall, was examined for three values of thrust augmentation. The onset of blade stall is shown to be delayed to higher airspeed by the application of thrust augmentation; the extent of the delay increases with load factor. For a given amount of thrust augmentation, the load factor in transient maneuvers is shown to be higher than for steady accelerated flight conditions.

The dynamic response of the helicopter in pitch and yaw to simulated gust inputs was examined for various combinations of thrust augmentation and airspeed. Thrust augmentation tends to decrease control sensitivity and to provide increased damping about both pitch and yaw axes following a disturbance.

Qualitative pilot opinion indicates that the helicopter is generally easier to fly as thrust augmentation is added.

CONCLUSIONS

From the results obtained during this test program, it is concluded that:

The application of horizontal thrust augmentation to rotary-wing aircraft, previously shown to be effective in delaying the onset of retreating blade stall to higher airspeeds in unaccelerated flight, is shown to be similarly effective for accelerated flight maneuvers. The influence of horizontal thrust augmentation in delaying the onset of stall becomes greater as the load factor is increased.

The maximum maneuver load factor is strongly affected by the character of the maneuver; coordinated turns, where a steady load factor is developed, were limited by retreating blade stall at lower load factors than were achieved in pull-up maneuvers developing transient load factors.

The longitudinal stability characteristics of the thrust-augmented research helicopter are similar to those of the standard UH-2. Increasing airspeed reduces the static longitudinal stability of the helicopter, and adding thrust augmentation tends to increase damping in pitch and reduces control sensitivity.

The helicopter responds to a simulated side gust with a motion characteristic of the Dutch roll mode. This motion is more highly damped as thrust augmentation is increased and appears to be relatively unaffected by airspeed.

INTRODUCTION

On 27 June 1963 a contract was awarded to Kaman Aircraft Corporation for the design and modification of a UH-2 helicopter to incorporate a YJ85-5 turbojet engine for horizontal thrust augmentation. A flight test program was subsequently conducted to evaluate the behavior of a fully articulated, servo-flap controlled rotor at speeds up to the 180- to 200-knot regime. The results of this program, reported in Reference 2, show the limit airspeed envelope as determined by blade stall or compressibility effects for steady unaccelerated flight.

In August 1964 a supplemental flight program was initiated to investigate the effect of maneuver load factor on the limit airspeed and to examine the dynamic response of the helicopter to gust inputs about both the pitch and yaw axes at various airspeeds and levels of thrust augmentation.

DESCRIPTION OF THE TEST VEHICLE

The test vehicle is a standard UH-2 helicopter (BuNo. 147978), reconfigured with a YJ85-5 jet engine for horizontal thrust augmentation, and is the same aircraft used for research conducted under USATRECOM Contract DA 44-177-AMC-105(T) reported in Reference 2. Incorporation of main rotor blades without the extensive instrumentation and tufting of the original blades was accomplished prior to testing.

Jet Engine Installation

A YJ85-5 engine, without afterburner, is mounted midway along the right side of the helicopter. The engine is suspended from a pylon cantilevered from two increased-depth structural frames inside the aft cabin area of the aircraft. An air inlet with a straight section equivalent to the compressor inlet diameter is mounted to the forward flange of the engine. The jet engine thrust is controlled through a mechanical system operated from a conventional throttle quadrant located on the lower console between the pilot and copilot. Pertinent parameters for monitoring jet engine operation are displayed on a centrally located panel adjacent to the standard aircraft instrument panel.

External Configuration

In addition to the jet engine installation, the test vehicle differs externally from a standard UH-2 by the omission of a section of the upper tail rotor gearbox cowling necessitated by the tail rotor slip-ring installation and by a reindexing of the horizontal stabilizer chord line from 10 degrees to 7 degrees, leading edge up, relative to the aircraft waterline.

The only control system deviation required was a 7-percent change in lateral cyclic rigging to offset the shift in lateral center of gravity associated with the jet engine installation. The aircraft fuel system configuration was somewhat modified by installation of higher capacity fuel pumps for the jet engine and the additional plumbing required. To offset the additional weight of the YJ85-5 engine installation, radio and navigational equipment considered unnecessary to the program was removed.

A fixture was installed on the longitudinal cyclic stick to aid in simulating gust inputs. The fixture allowed rapid stick input of a predetermined amount and return to trim with no overshoot.

TEST INSTRUMENTATION

Test instrumentation was installed to record flight test data pertinent to controllability, stability, rotor loads, and aircraft vibrations at the test conditions flown. This consisted of a multichannel telemetry system, recording oscillograph, and a 35mm photopanel with the appropriate sensors for recording the following parameters:

- Airspeed
- Altitude
- Pitch and roll attitude
- Yaw attitude and rate
- Outside air temperature
- T-58 - engine RPM, EGT, and torque
- T-58 - engine mount loads
- YJ85 - engine RPM, EGT, and thrust
- YJ85 - engine mount loads and accelerations
- Main rotor transmission mount loads and accelerations
- Cyclic, directional, and collective control positions
- Pilot seat acceleration
- C.G. acceleration
- Main rotor RPM and azimuth position
- Main rotor hub torque
- Main rotor flapping
- Main rotor flapwise and chordwise bending moments
- Main rotor servo-flap flapwise bending moments
- Tail rotor RPM and azimuth
- Tail rotor flapping angle
- Tail rotor flapwise and chordwise bending moments
- Horizontal stabilizer flapwise and chordwise bending moments

Instrumentation of selected critical parameters was provided to permit continuous telemetry monitoring in addition to the recorded oscillograph data to assure consistency with structural capability and safety of flight.

Calibration

All instrumented items were calibrated in the laboratory prior to installation on the aircraft. Preflight and postflight calibrations were made to insure the validity of data from each flight. All data presented are corrected for instrument and installation errors.

FLIGHT TESTS

Flight tests were conducted to investigate the following series of conditions as a function of airspeed and auxiliary jet thrust at 99-100 per cent rotor r.p.m:

a. The effect of thrust augmentation on the transient normal load factors in pull-up maneuvers as limited by retreating blade stall.

b. The effect of thrust augmentation on the steady-state load factors developed in turns as limited by retreating blade stall.

c. Longitudinal response to simulated gust inputs (longitudinal control pulse inputs) forward and aft of trim.

d. Lateral/directional response to simulated gust inputs (rudder pedal pulse inputs right and left).

Flight test data were obtained for three values of thrust augmentation throughout a range of airspeeds to define adequately the transient and steady-state load factors as limited by retreating blade stall for the conditions specified in Reference 1, with a single exception. The exception was the 145-knot maximum steady load factor condition using 2400 pounds of thrust augmentation, which was not attained due to the excessively high bank angle.

All flight testing was conducted at between a 2000- and 3000-foot density altitude and with a takeoff gross weight of approximately 9200 pounds and an aft center-of-gravity position (Station 173).

The flight testing, which was initiated on 27 August 1964 and completed on 22 September 1964, included 18 flights involving 11.5 hours of aircraft time. A summary of all data flights accomplished to complete the program is presented in Table I.

FLIGHT TEST RESULTS

EFFECT OF THRUST AUGMENTATION ON MANEUVER LOAD FACTOR

The flight test data obtained to evaluate the maneuverability flight envelope as defined by retreating blade stall are presented in Table I. These data are depicted graphically in Figure 2. All test points shown are corrected to an aircraft gross weight of 8900 pounds and 100-percent rotor speed.

The transient load factor test points were obtained during pull-up maneuvers. A typical time history of such a maneuver, which defines a limit load factor at a given speed and thrust augmentation level, is shown in Figure 3. This represents the final maneuver in a series performed during the buildup to the limit load factor with increasing increments of collective and cyclic control from trimmed level flight. The significant indicator to the pilot that a limit load factor had been reached was an increase in pilot seat vibratory acceleration at main rotor frequency. This vibration buildup started at the point of maximum load factor and increased in amplitude until recovery was initiated. As shown in Figure 2, several limit transient load factor points were obtained for a given airspeed and thrust augmentation level. The spread in the data, which is particularly apparent at the higher load factor levels, reflects the varying depth of penetration beyond the onset of blade stall.

The maximum load factor which can be attained in a coordinated turn was established by flying a gradually tightening turn until increasing vibratory acceleration indicated the onset of blade stall. A time history of a typical turn maneuver is presented in Figure 4 where the abrupt increase in vibratory acceleration at one and four times the main rotor frequency is clearly evident.

It is evident from Figure 2 that thrust augmentation increases the stall-limited transient and steady-state load factor levels. At a given level of thrust augmentation, the transient load factor obtained is higher than the steady-state levels. This is attributed primarily to the difference in main rotor horsepower requirements for the two conditions. The pull-up transient maneuvers are accomplished at lower main rotor power levels, which results in lower blade angles of attack as compared to steady-state maneuvers at the same load factor. This relationship of the load factor stall limit to main rotor power level is consistent with the unaccelerated level flight data of Reference 2, which showed that, at a given airspeed, reducing main rotor power by increasing thrust augmentation yields a greater stall margin.

In addition to the above-noted relationship of stall-limited load factor levels to main rotor power, the influence of main rotor tip path plane pitch velocity in maneuvers (as discussed in Reference 3) would be expected to contribute to the establishment of the limit point. However, the flight test program did not include the acquisition of data necessary to determine the relative influence of pitch rate.

It is apparent from Figure 2 that, at higher load factor levels, a greater stall relief is obtained with increasing levels of jet thrust augmentation, as evidenced by the steeper slope of the load factor versus airspeed line for higher jet thrust conditions. This is attributed to the reduced main rotor power associated with higher thrust which has the effect of moving the critical angle of attack region on the blade inboard where the dynamic pressure is lower. Stall in the more inboard blade region imposes a lesser penalty on total lift; this results in an improved trade-off of airspeed for load factor.

VIBRATORY LOADS DURING MANEUVERS

The time histories plotted in Figures 3 and 4 include chordwise and flapwise vibratory bending moments at blade Stations 43.5 and 190, respectively. Examination of these figures indicates that, in a transient maneuver, the build-up of blade bending moments is affected by increasing load factor as well as the response of the blade to control input and the onset of retreating blade stall. In coordinated turns similar effects can be seen although the time required to complete the maneuver is an order of magnitude higher than for a transient pull-up. Vibratory loads measured at selected locations throughout the airframe exhibited similar response to transient and steady-static maneuvers. The characteristics noted for the jet augmented helicopter are in good agreement with those determined on the standard UH-2 in similar maneuvers.

EFFECT OF THRUST AUGMENTATION ON DYNAMIC STABILITY

The dynamic response of the helicopter in pitch and yaw to simulated gust input was examined for the various combinations of airspeed and thrust augmentation tabulated in Table II.

Longitudinal Response to Gust Input

The effect of a vertical gust, simulated by a pulse input of longitudinal cyclic control, is presented in Figures 5 through 10.

The helicopter appears to be quite sensitive to longitudinal control input, but, based on pilot evaluation, the sensitivity is decreased by increasing thrust augmentation. The pitching motion following the initial disturbance is influenced by both the magnitude of the disturbance and any subsequent cyclic stick motions. In five of the test conditions, the pulse inputs of longitudinal control were very close to 4 percent of total travel

from trim, and, subsequent to the pulse, the control was held constant until recovery control was applied. These cases, as shown in Figures 6, 8, and 9, are considered to best represent the response of the helicopter to a vertical gust input.

The effect of the rotor power/thrust augmentation trade-off on longitudinal gust response is illustrated by comparison of the pitching motion of Figures 6 and the 128-knot case of Figure 8. An increase in the period and response of the pitching motion at the higher thrust level is evident. This can be attributed to the reduction in static longitudinal stability, which would be expected at the higher thrust level. Such a reduction in static stability implies a decrease in critical damping and therefore an increase in damping ratio. The lower collective pitch associated with higher levels of thrust augmentation at a given airspeed would also be expected to increase pitch damping as discussed in Reference 4. This reference points out that the rotor damping moment about the helicopter center of gravity varies inversely with the ratio of collective pitch to the blade loading parameter, $C_{T/\sigma}$.

As expected, the effect of airspeed is to decrease static longitudinal stability. This is most evident in Figure 8 where it can be seen that, at 128 knots, the pitch attitude does not become divergent until after the first half-cycle, while at 137 knots, no tendency to return to trim is seen. This decrease in static stability is also apparent when the pitch attitude responses shown in Figure 9 are compared. It will be noted that, at 151 knots, the divergence tends to be more rapid than at 140 knots.

The net effect of the above-noted characteristics on the flying qualities of the helicopter appears to the pilot to be an improvement in dynamic longitudinal stability as thrust augmentation is increased at a given airspeed. Even at the highest trim airspeeds tested where the deterioration of static stability is most significant, the effect of reducing rotor power by adding thrust augmentation is to make the aircraft more docile and easier to fly.

The response of the helicopter to vertical gusts is accompanied by a roll motion for all conditions tested, as shown in Figures 5 through 10. This motion is attributed to the change in main rotor cone angle resulting from the lift change on the rotor when load factor is developed. Increased cone angle, for example, reduces the blade angle of attack at zero azimuth and increases it at the 180-degree azimuth. The resultant motion tilts the rotor disc to the right, which is a roll response to the right. Decreased cone angle will have the opposite effect.

Figure 11 shows the response of the standard UH-2 helicopter to a vertical gust disturbance. Comparison of this figure with Figure 7 shows the same general characteristics, although the period for a half-cycle is shorter for the standard helicopter. This may be attributable to its lower inertia and the above-noted effects on static stability.

Directional Response to Gust Input

Side gusts were simulated by pulse inputs of rudder pedal control. Results are presented in Figures 12 through 17 for all conditions investigated. Lateral cyclic inputs were applied to control the magnitude of the roll angle resulting from sideslip.

The helicopter responds with a motion characteristic of the Dutch roll mode with a period of 3 to 3.5 seconds. This motion is more heavily damped with increased jet thrust augmentation as illustrated by comparison of the 800-pound (Figures 12 and 13) and 1600-pound (Figures 14 and 15) thrust conditions at the same airspeed. This is attributed to the lower collective pitch associated with higher thrust augmentation which would be expected to increase the damping of the coupled roll motion, as discussed in Reference 4.

The effect of airspeed on the motion characteristics about the vertical axis is best seen by comparing the yaw rate curves for the 124 knot and 143 knot cases shown in Figure 14 for 1600 pounds thrust. From this comparison, it can be concluded that the effect of airspeed is small. This same conclusion can be reached by a study of Figure 16 with 2400 pounds of thrust at airspeeds of 145 and 160 knots.

Pilot comments relating to dynamic lateral directional characteristics confirm the presence of a neutrally stable Dutch roll mode which, if allowed to develop, would reach ± 12 degrees of roll. The motion was observed to be easily controlled with slight stick pressure.

The motion of the helicopter in response to side-gust inputs includes rotation about the pitch axis. This motion is easily controlled and is apparently a consequence of the pitch instability previously noted under the discussion of longitudinal response to gust inputs. While examining the directional stability at 134 knots CAS with 800 pounds of thrust augmentation, the pitching motion was allowed to develop. The results are presented in Figure 12 where it can be seen that forward cyclic and reduced collective were required to recover. Although the airspeed dropped from 134 knots to 120 knots from the beginning of the maneuver to the point where collective control was applied, a load factor of 1.45 was developed as a consequence of the pitch attitude change which caused entry into the retreating blade stall region.

REFERENCES

1. Contract DA-44-177-AMC-151(T), Modification 1, August 1964.

2. Kaman Aircraft Corporation Report Number R-527B, UH-2 Helicopter High-Speed Flight Research Program Utilizing Jet Thrust Augmentation, November 1964.

3. Brown, E. L., Schmidt, P.S., "The Effect of Helicopter Pitching Velocity on Rotor Lift Capability," Journal of the American Helicopter Society, October 1963.

4. Amer, Kenneth B., Theory of Helicopter Damping in Pitch or Roll and a Comparison With Flight Measurements, NACA Technical Note 2136, October 1950.

TABLE I

SUMMARY OF MANEUVERABILITY TEST POINTS

FLT/REC.	TYPE	TAS(KT)	T_J(LB)	MRHP	Load Factor
104/2	Transient	113.1	1600	388	2.26
/4	"	114.2	1600	367	2.33
/5	"	116.3	1600	334	2.51
/6	"	115.2	1600	455	2.45
/7	"	114.2	1600	378	2.37
117/1	"	132.5	1600	484	1.77
/2	"	134.6	1600	434	1.82
/3	"	132.5	1600	496	1.83
105/1	"	147.4	2400	82	2.03
/2	"	153.5	2400	234	1.85
117/6	"	155.9	2400	367	1.85
/7	"	156.0	2400	279	1.89
/8	"	156.0	2400	423	1.70
105/3	"	171.3	2400	268	1.56
117/9	"	168.9	2400	511	1.55
/10	"	172.6	2400	498	1.65
109/3	Steady State	119.8	800	890	1.58
108/7	"	128.3	800	807	1.43
/8	"	138.2	800	917	1.27
120/1	"	135.6	1600	604	1.75
/2	"	140.0	1600	667	1.66
109/7	"	149.1	1600	960	1.27
/9	"	149.3	2400	250	1.71
/11	"	173.7	2400	625	1.18

TABLE II

SUMMARY OF DYNAMIC STABILITY TEST POINTS

FLT/REC.	CONTROL INPUT	TAS(KT)	T_J (LB)	MRHP
107/1	Aft Longitudinal Cyclic Pulse	131.4	800	921
/2	"	134.5	1600	454
/3	"	146.7	1600	581
/4	"	148.1	2400	265
/6	"	157.3	2400	267
111/1	Forward Longitudinal Cyclic Pulse	134.8	800	820
/2	"	131.7	1600	419
/3	"	143.0	1600	507
/4	"	148.4	2400	245
/5	"	159.6	2400	279
113/1	Right Pedal Pulse	127.8	800	750
/4	"	140.3	800	1024
/6	"	128.9	1600	315
/8	"	139.1	1600	465
/11	"	149.0	1600	565
/17	"	150.4	2400	212
/19	"	165.8	2400	332
113/3	Left Pedal Pulse	127.2	800	760
/5	"	135.2	800	824
/7	"	128.9	1600	315
/10	"	134.9	1600	492
/14	"	151.4	1600	593
/18	"	153.6	2400	224
/22	"	164.9	2400	353

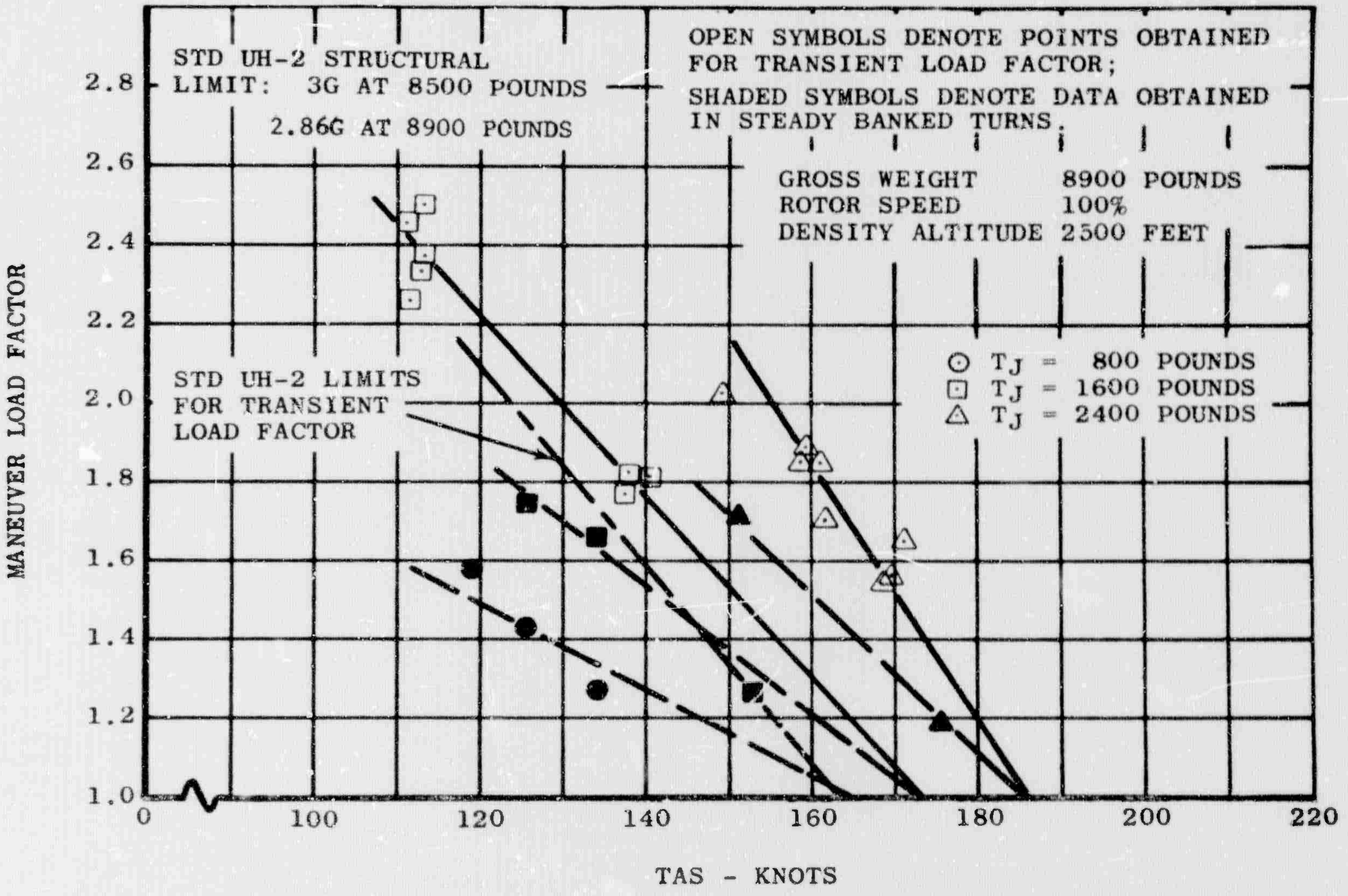

Figure 2. MAXIMUM MANEUVER LOAD FACTOR AS AFFECTED BY THRUST AUGMENTATION

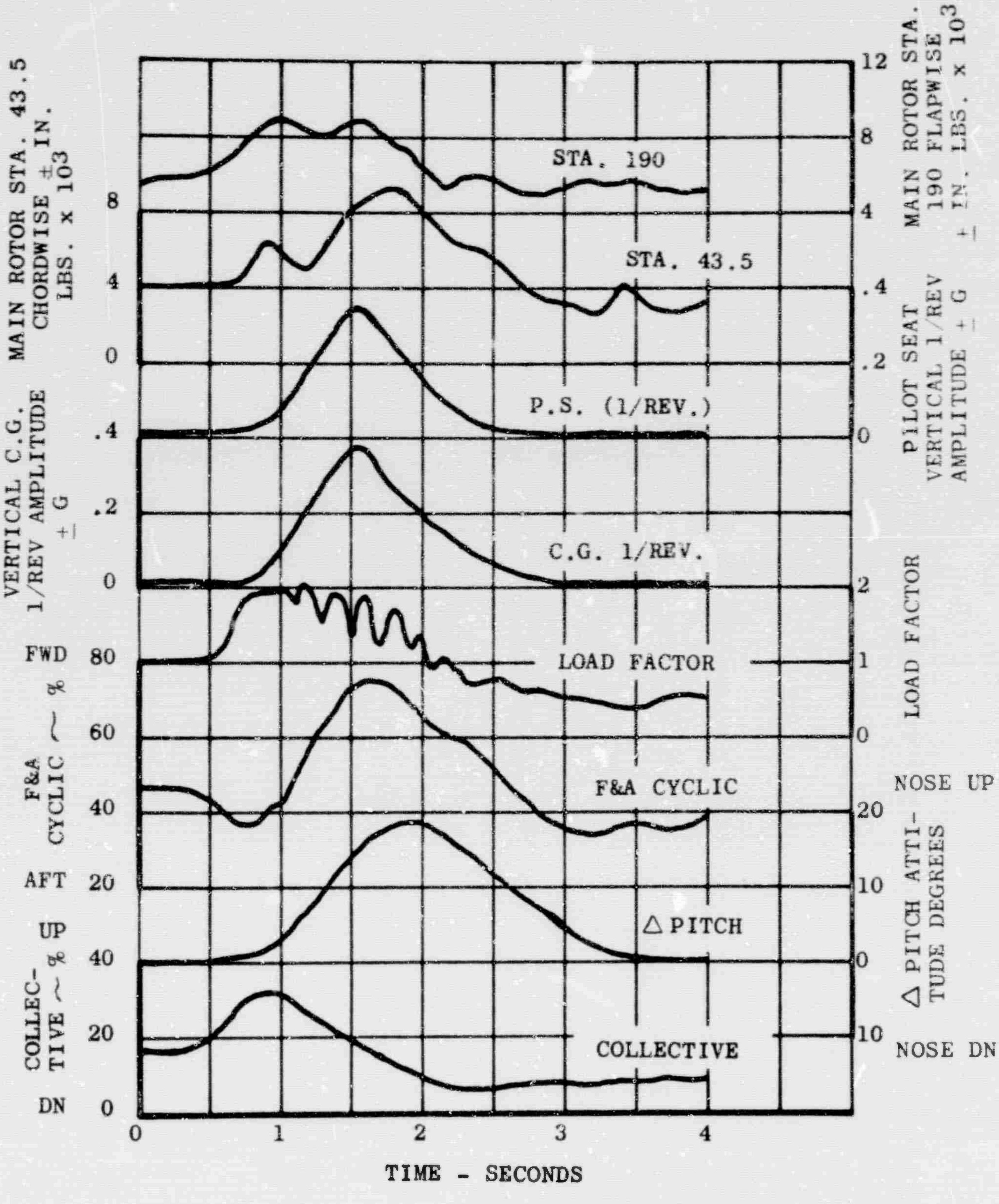

Figure 3. TIME HISTORY OF DEVELOPMENT OF TRANSIENT NORMAL LOAD FACTOR, FLIGHT RECORD 105/1, TABLE I

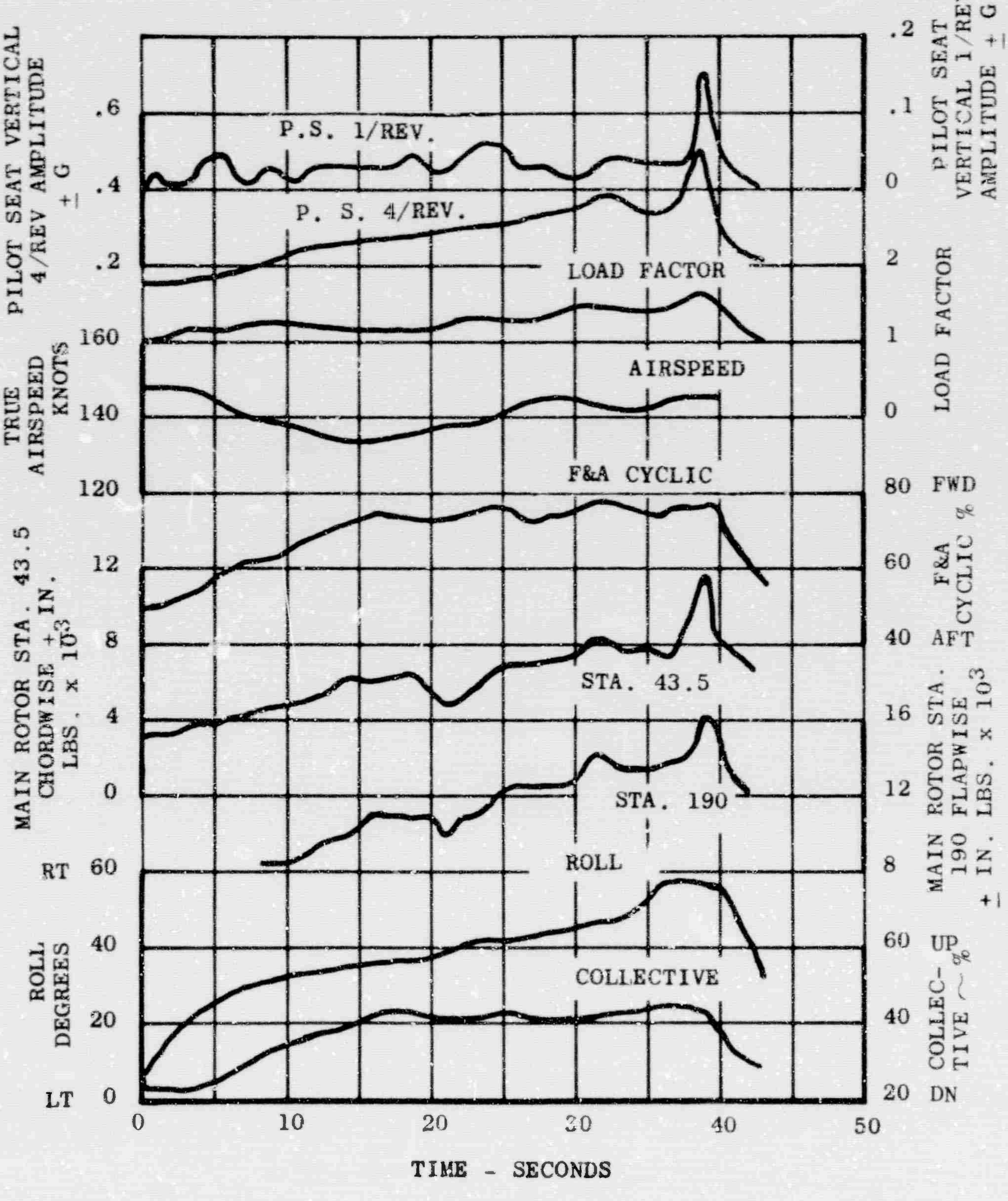

Figure 4. TIME HISTORY OF DEVELOPMENT OF STEADY-STATE NORMAL LOAD FACTOR, FLIGHT RECORD 109/9, TABLE I

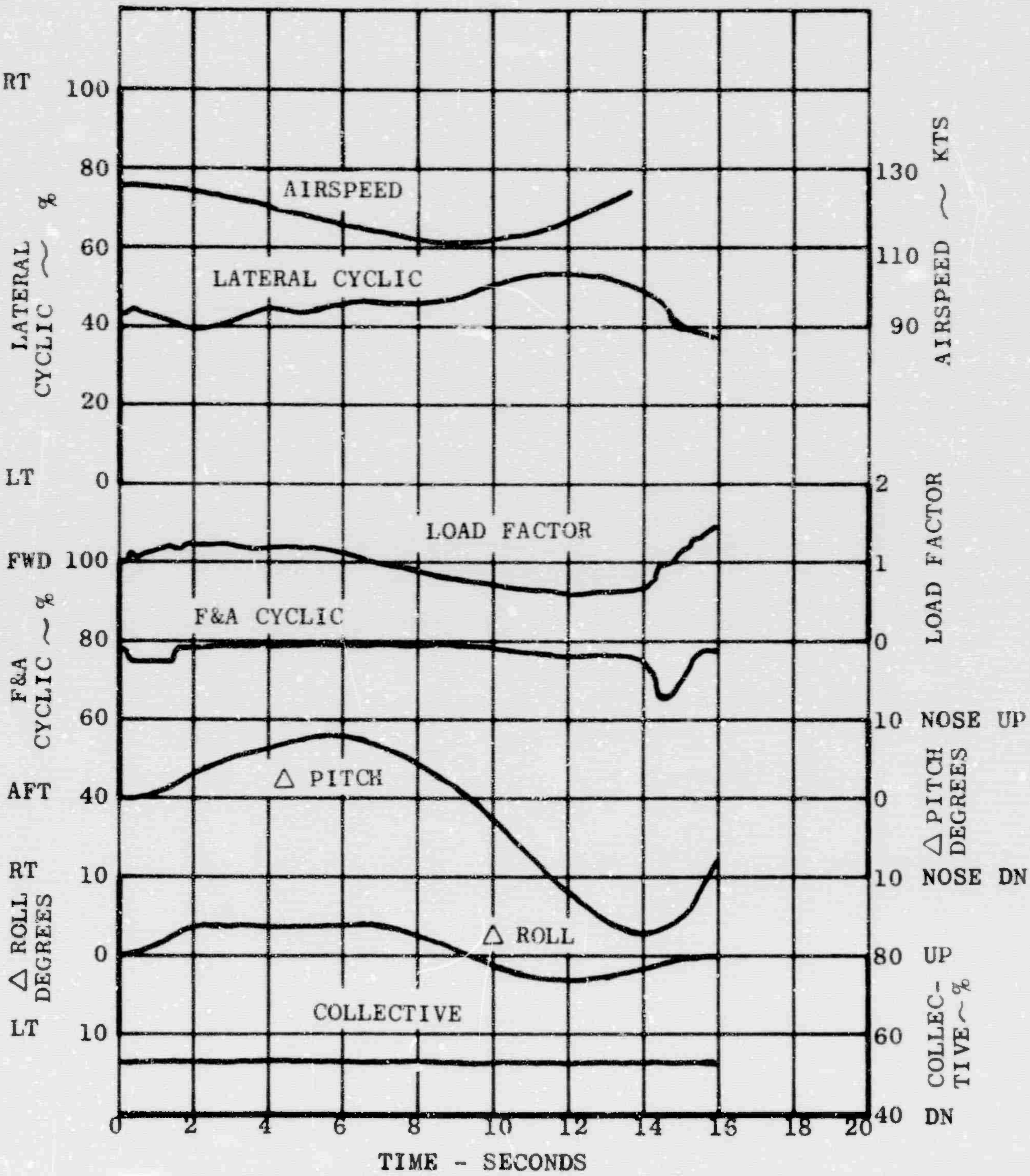

Figure 5. HELICOPTER RESPONSE TO A SIMULATED VERTICAL UP GUST, CAS = 126 KNOTS, T_J = 800 POUNDS

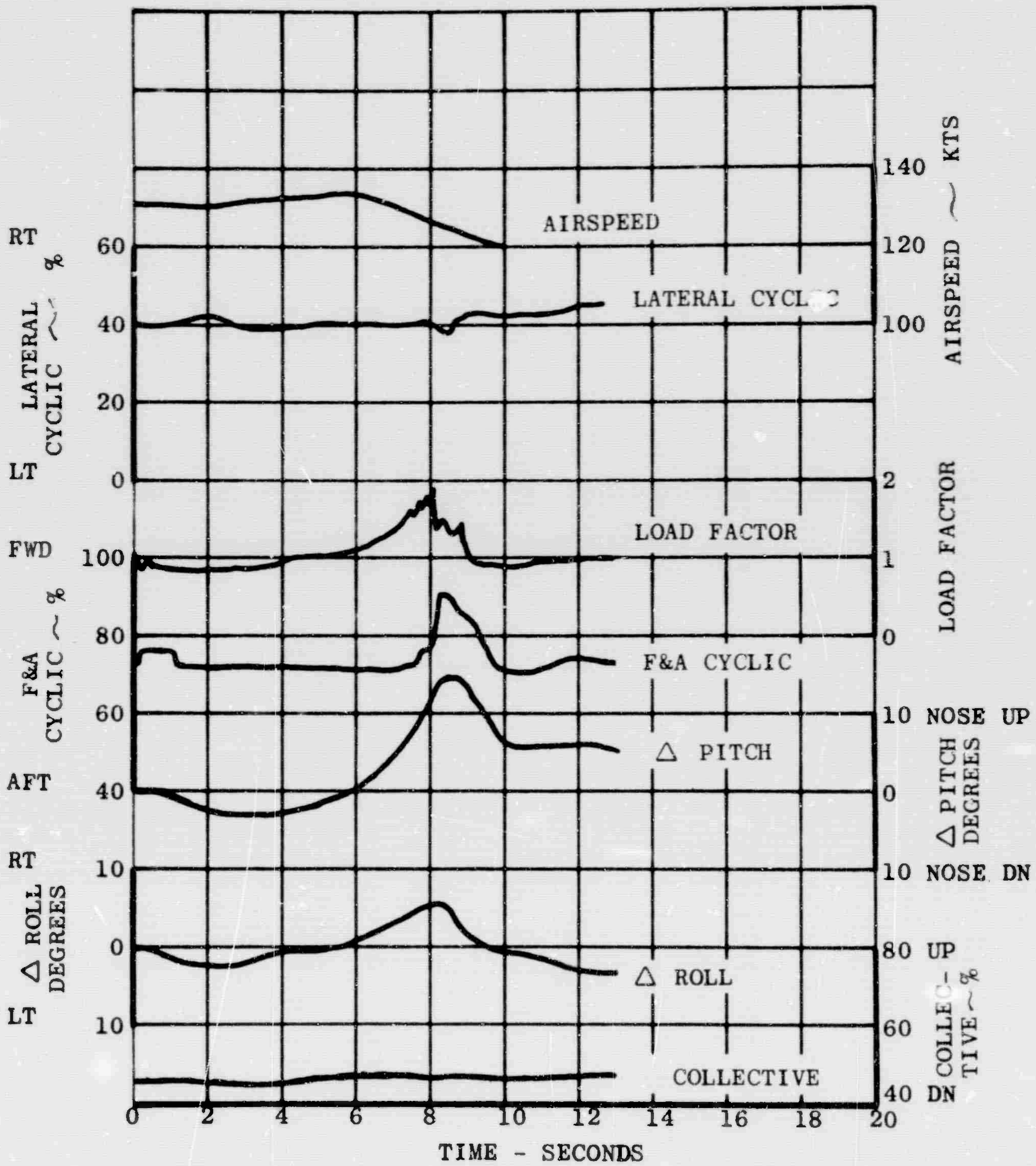

Figure 6. HELICOPTER RESPONSE TO A SIMULATED VERTICAL DOWN GUST, CAS = 131 KNOTS, T_J = 800 POUNDS

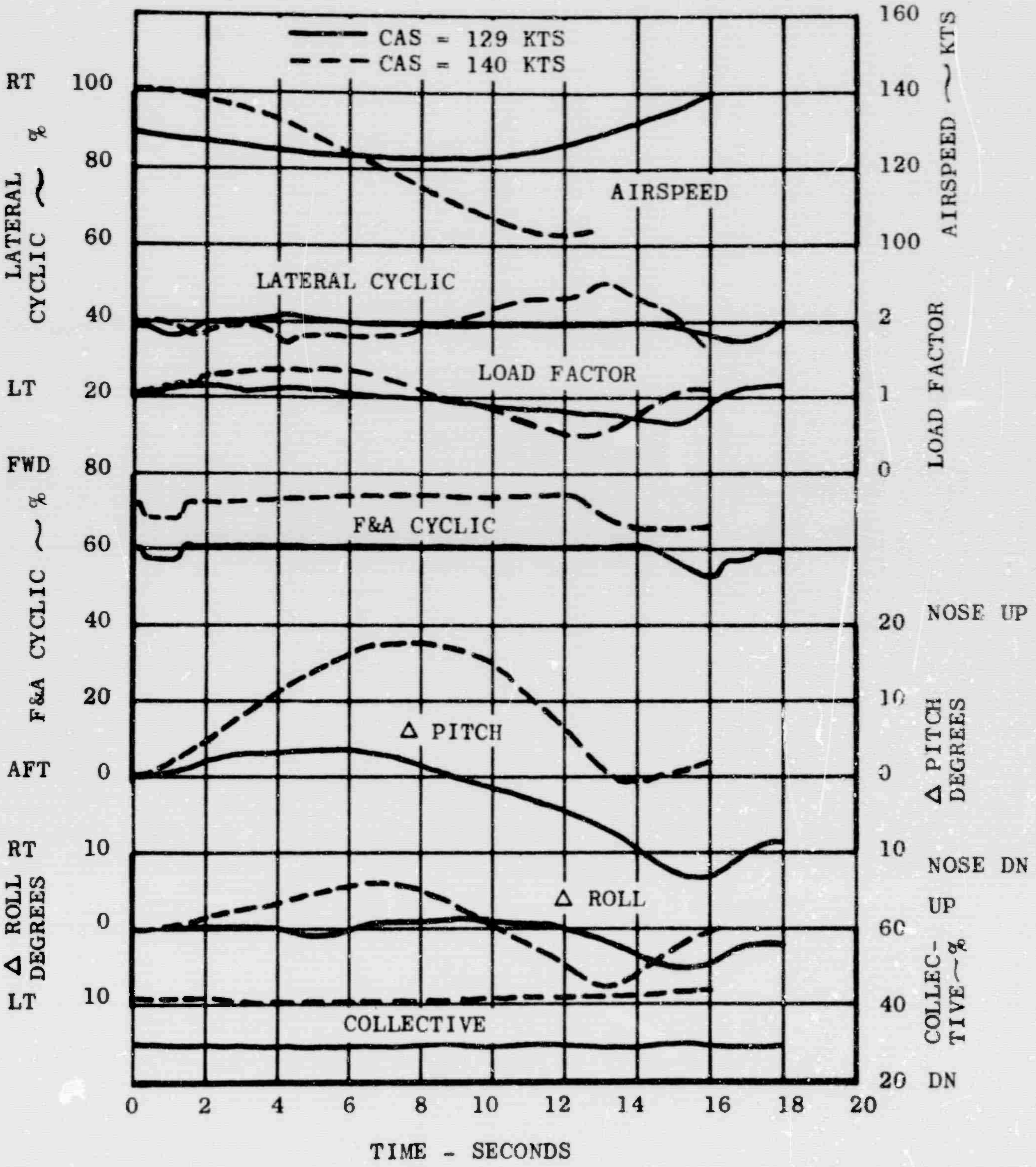

Figure 7. HELICOPTER RESPONSE TO A SIMULATED VERTICAL UP GUST, T_J = 1600 POUNDS

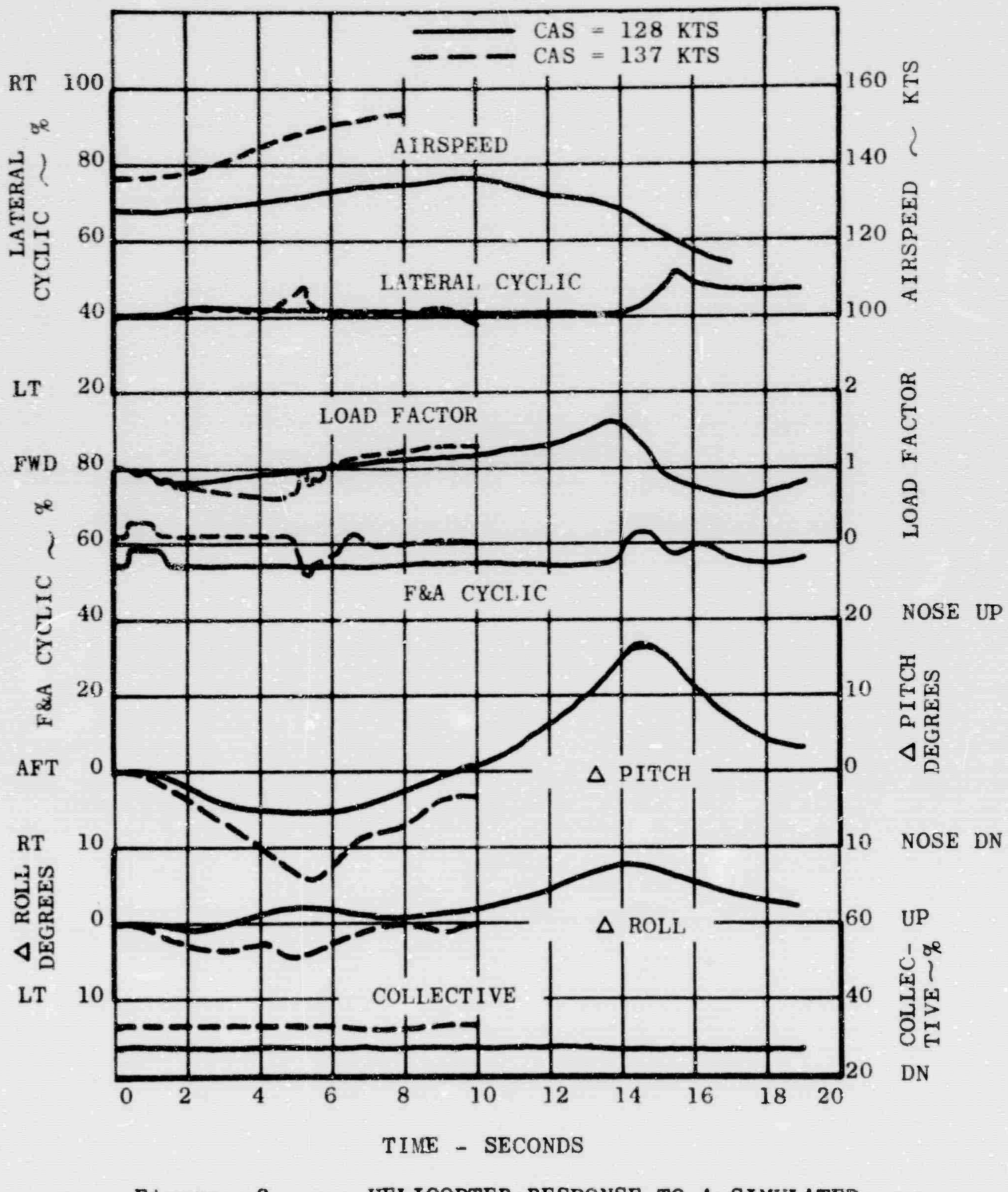

Figure 8. HELICOPTER RESPONSE TO A SIMULATED VERTICAL DOWN GUST, T_J = 1600 POUNDS

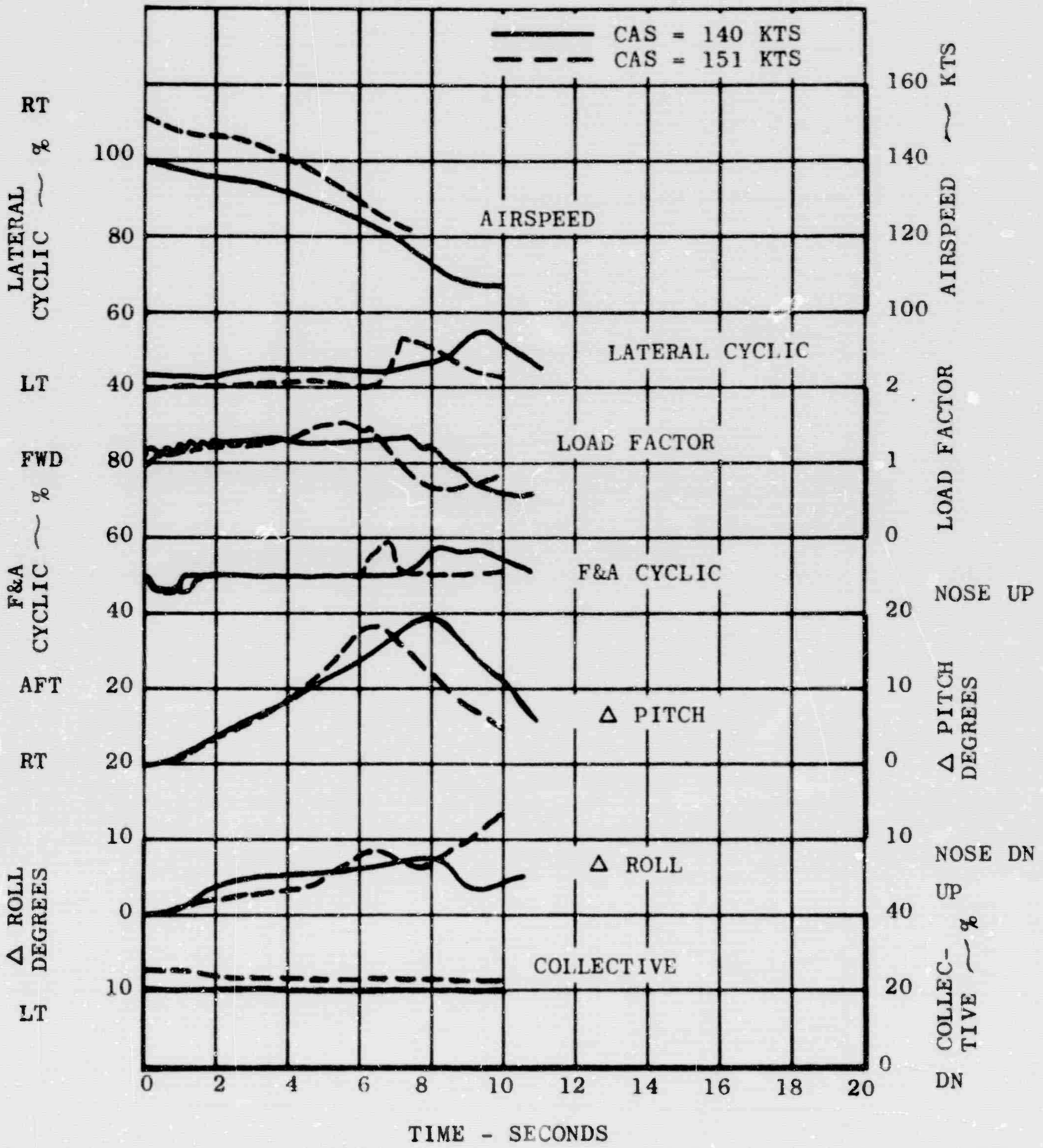

Figure 9. HELICOPTER RESPONSE TO A SIMULATED VERTICAL UP GUST, T_J = 2400 POUNDS

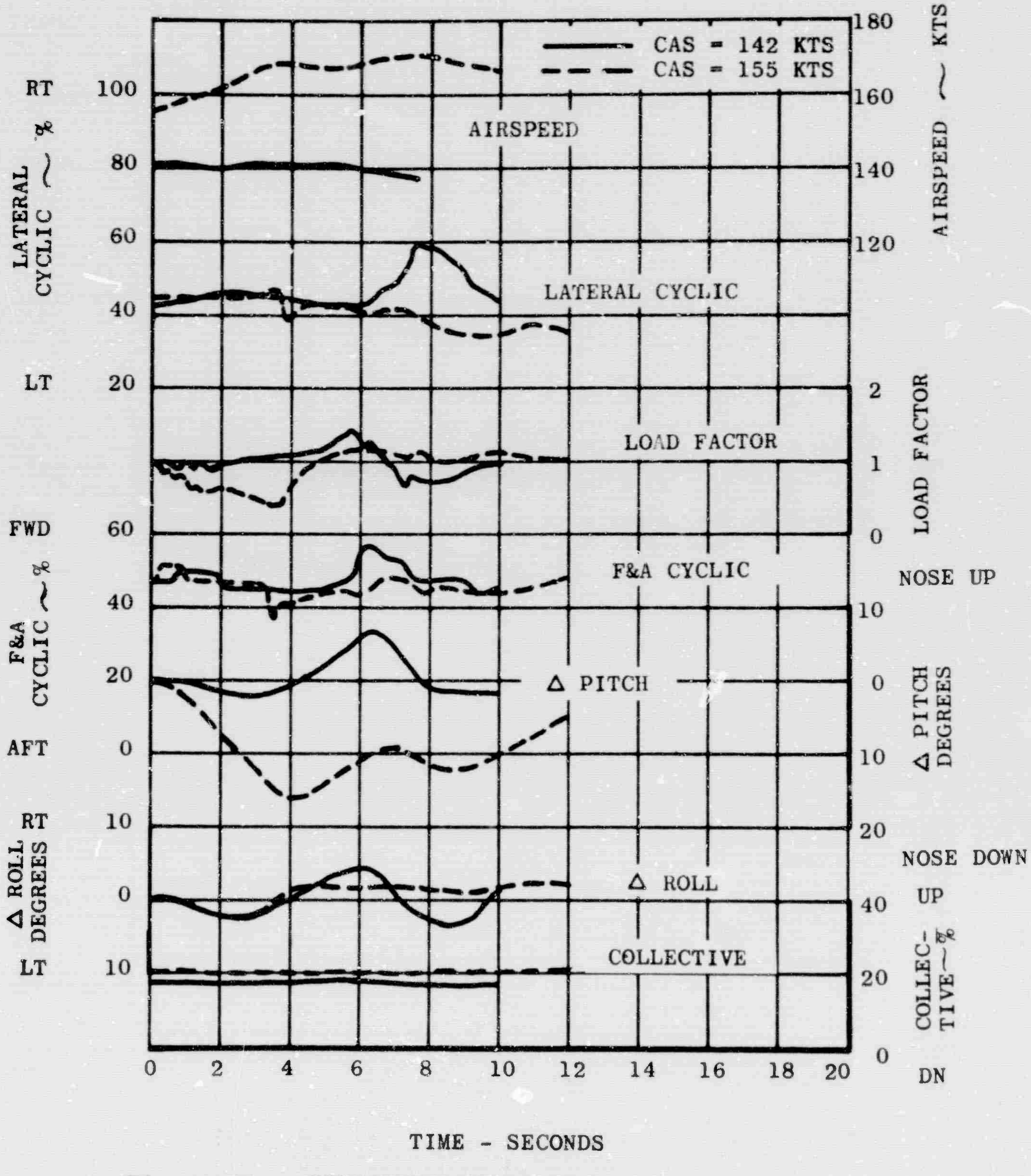

Figure 10. HELICOPTER RESPONSE TO A SIMULATED VERTICAL DOWN GUST, T_J = 2400 POUNDS

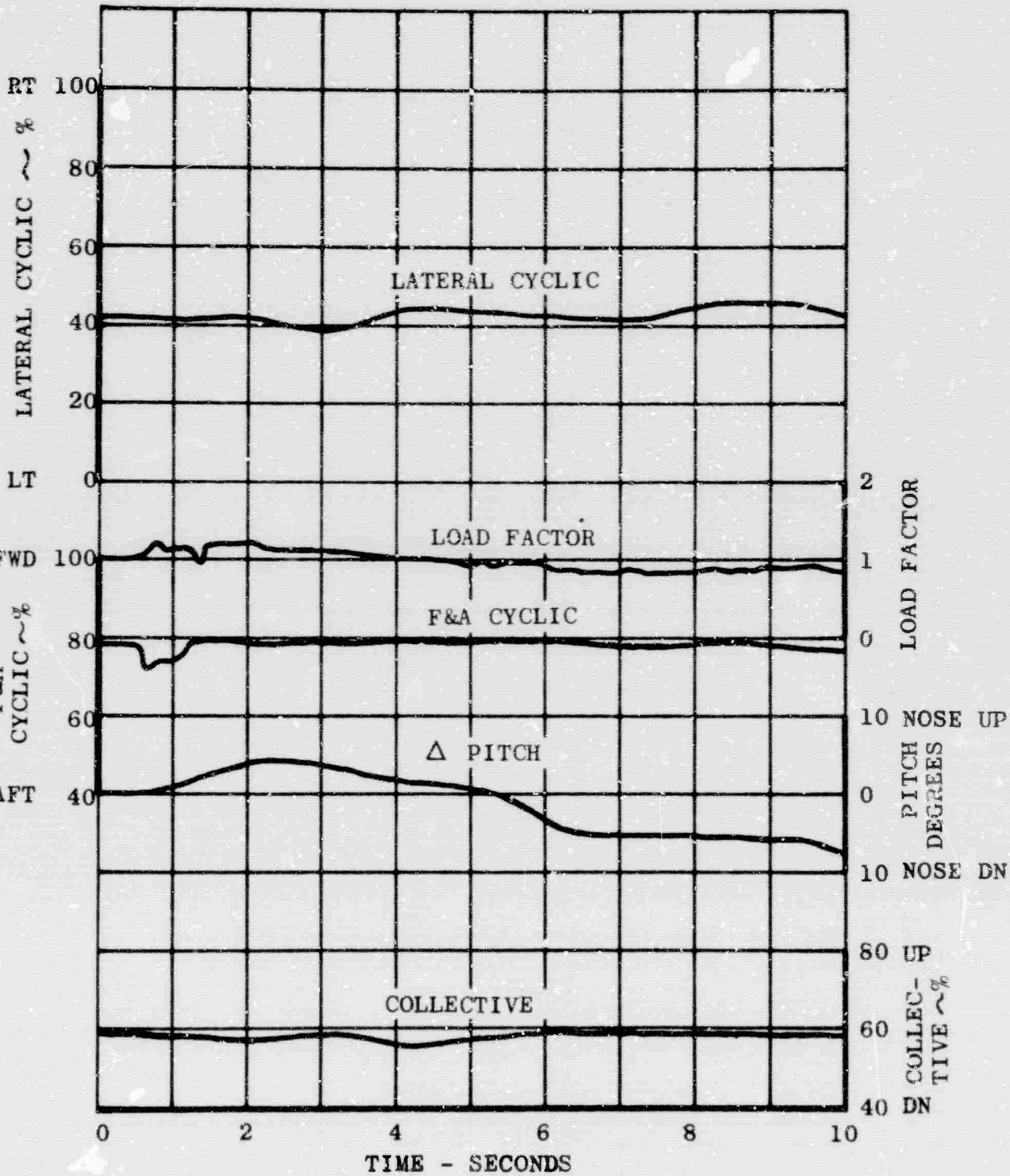

Figure 11. STANDARD UH-2 HELICOPTER RESPONSE TO A SIMULATED VERTICAL UP GUST, CAS = 121 KNOTS

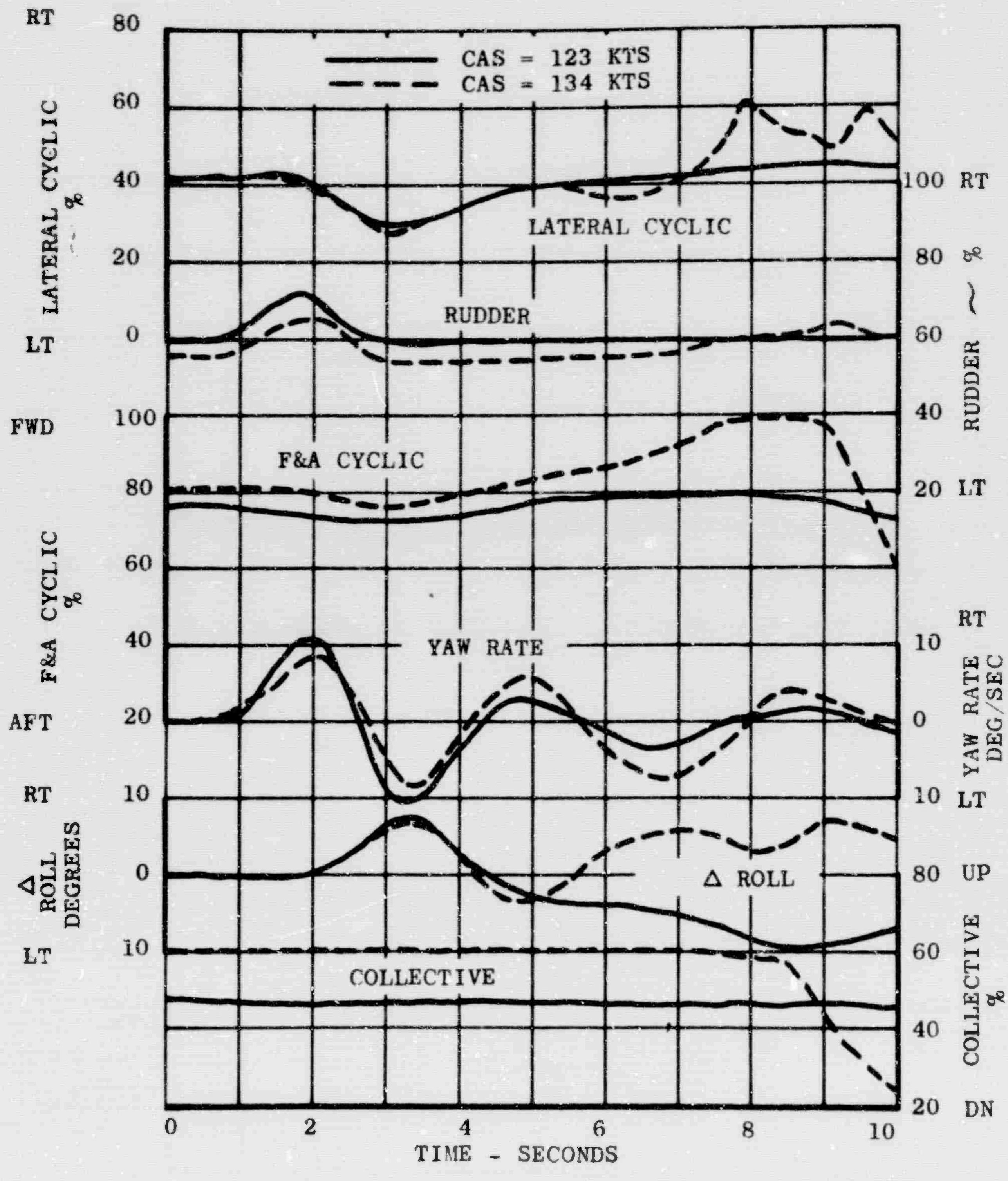

Figure 12. HELICOPTER RESPONSE TO A SIMULATED SIDE GUST FROM THE LEFT, T_J= 800 POUNDS

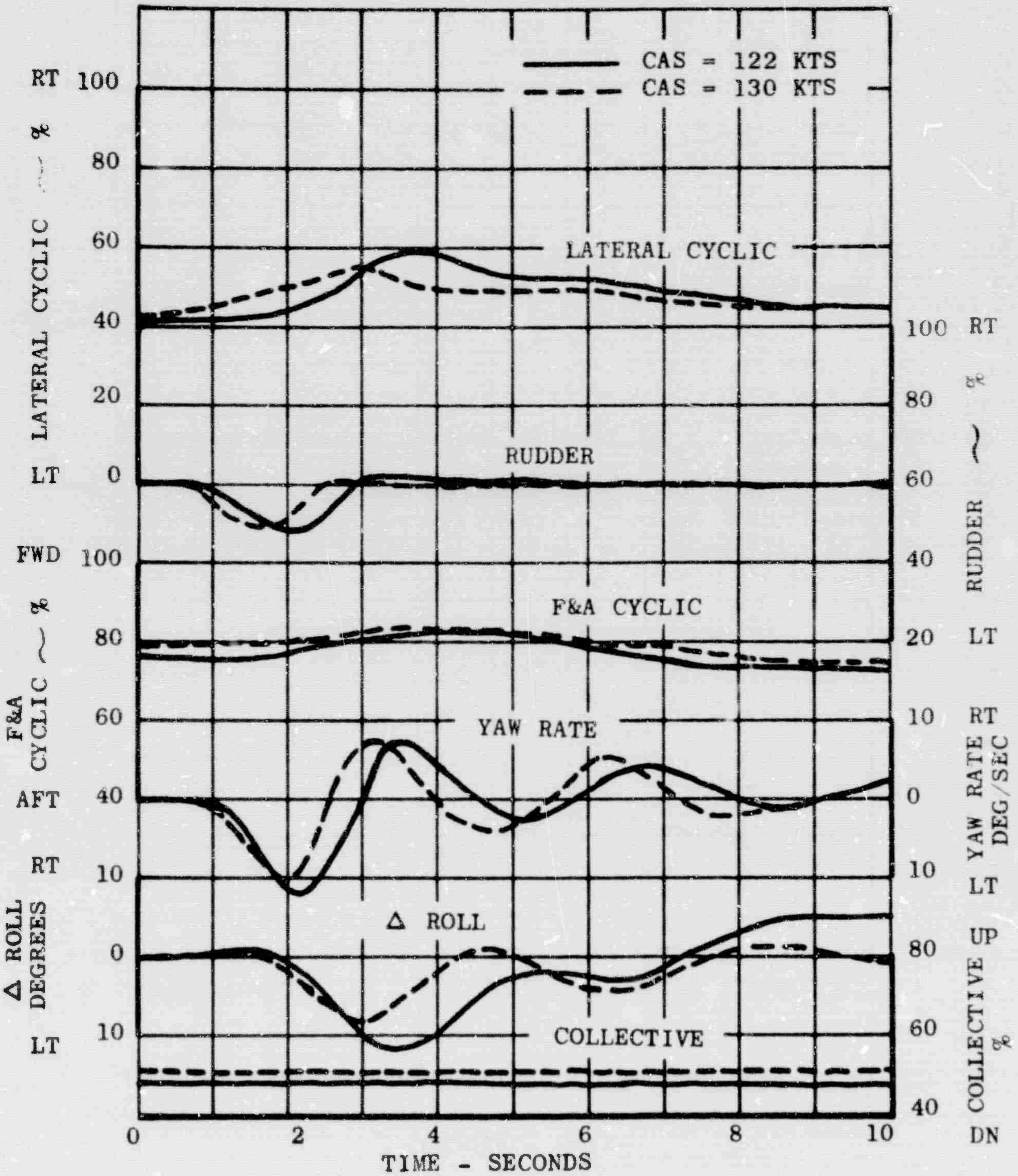

Figure 13. HELICOPTER RESPONSE TO A SIMULATED SIDE GUST FROM THE RIGHT, T_J = 800 POUNDS

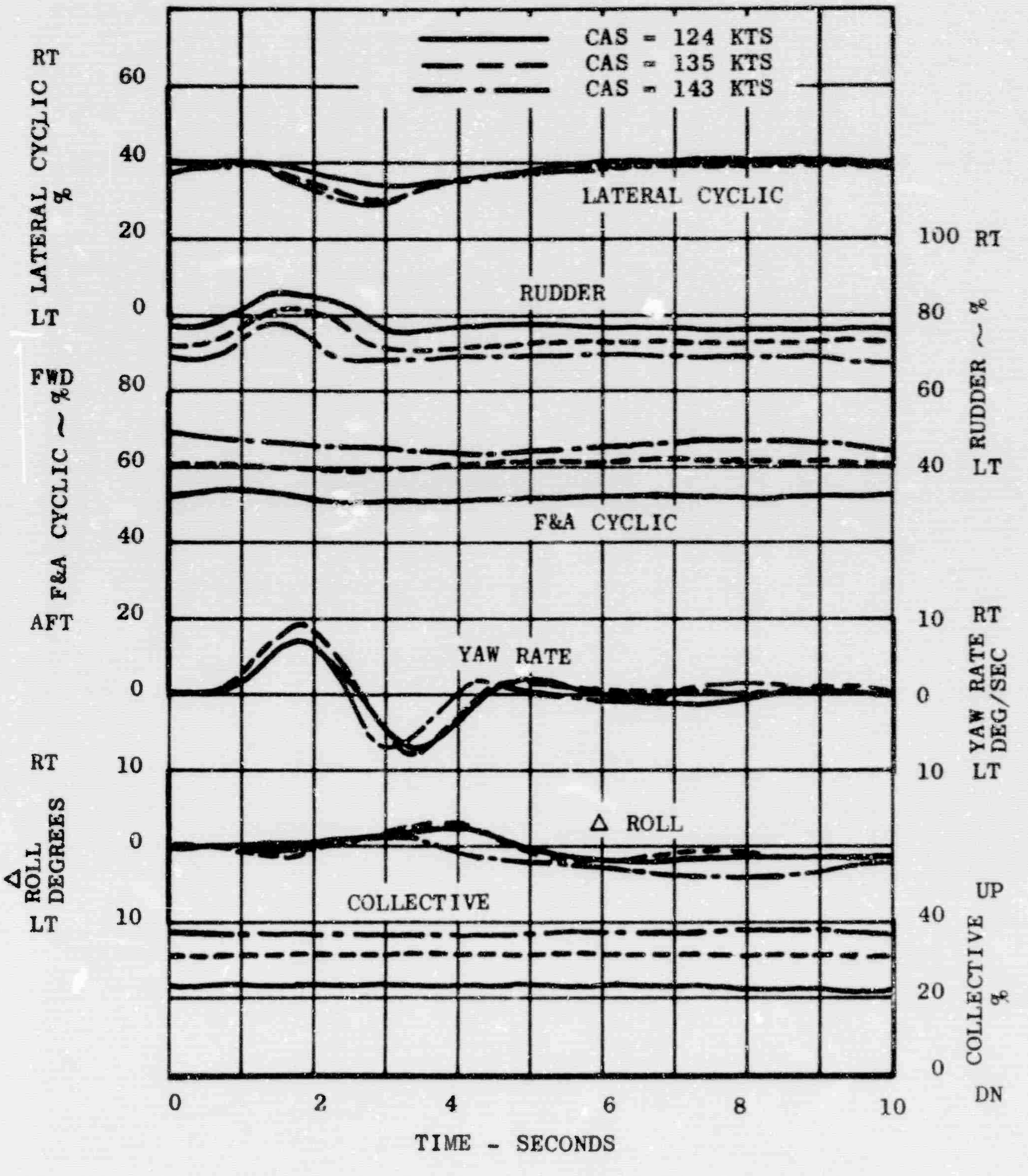

Figure 14. HELICOPTER RESPONSE TO A SIMULATED SIDE GUST FROM THE LEFT, T_J = 1600 POUNDS

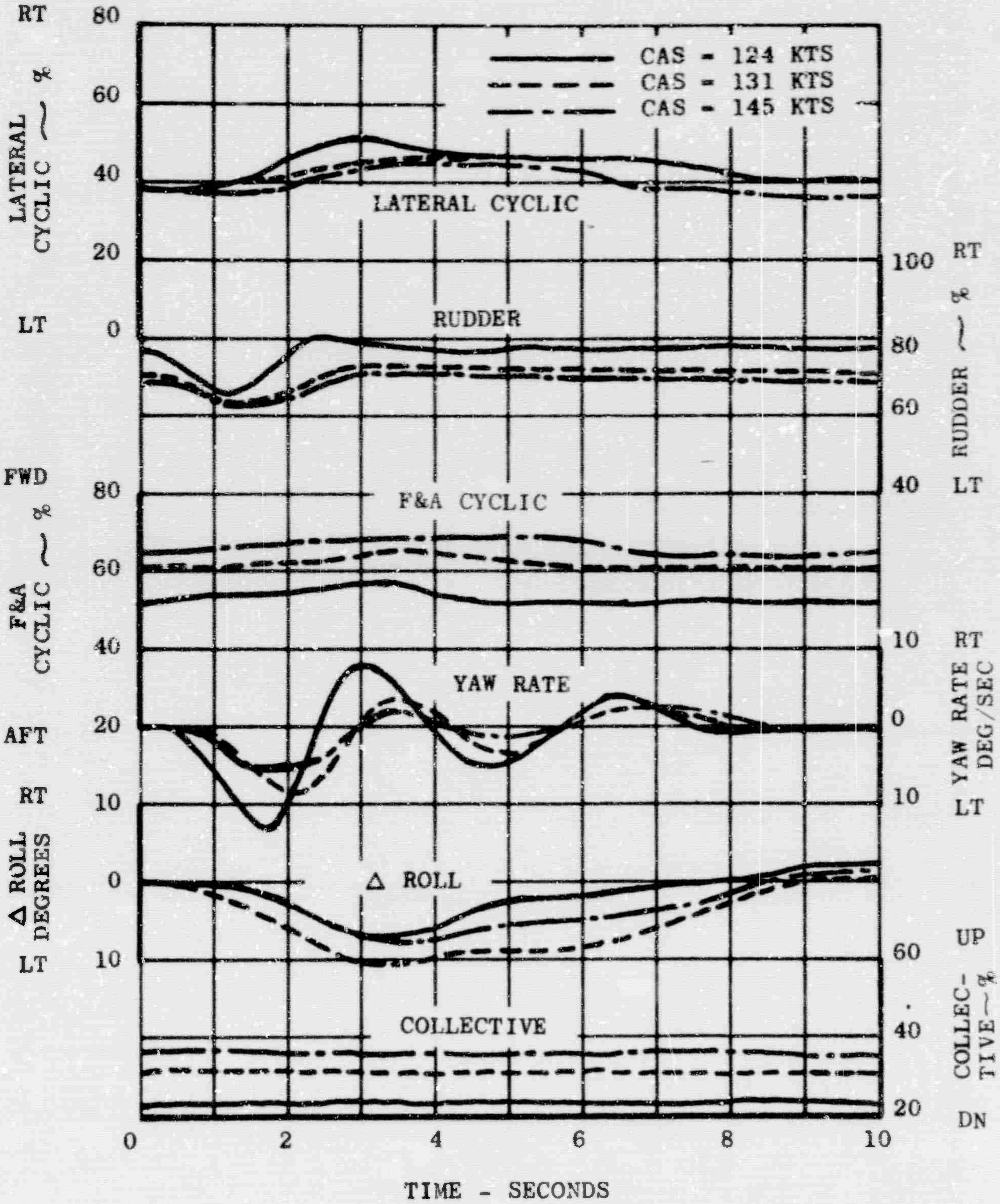

Figure 15. HELICOPTER RESPONSE TO A SIMULATED SIDE GUST FROM THE RIGHT, T_J = 1600 POUNDS

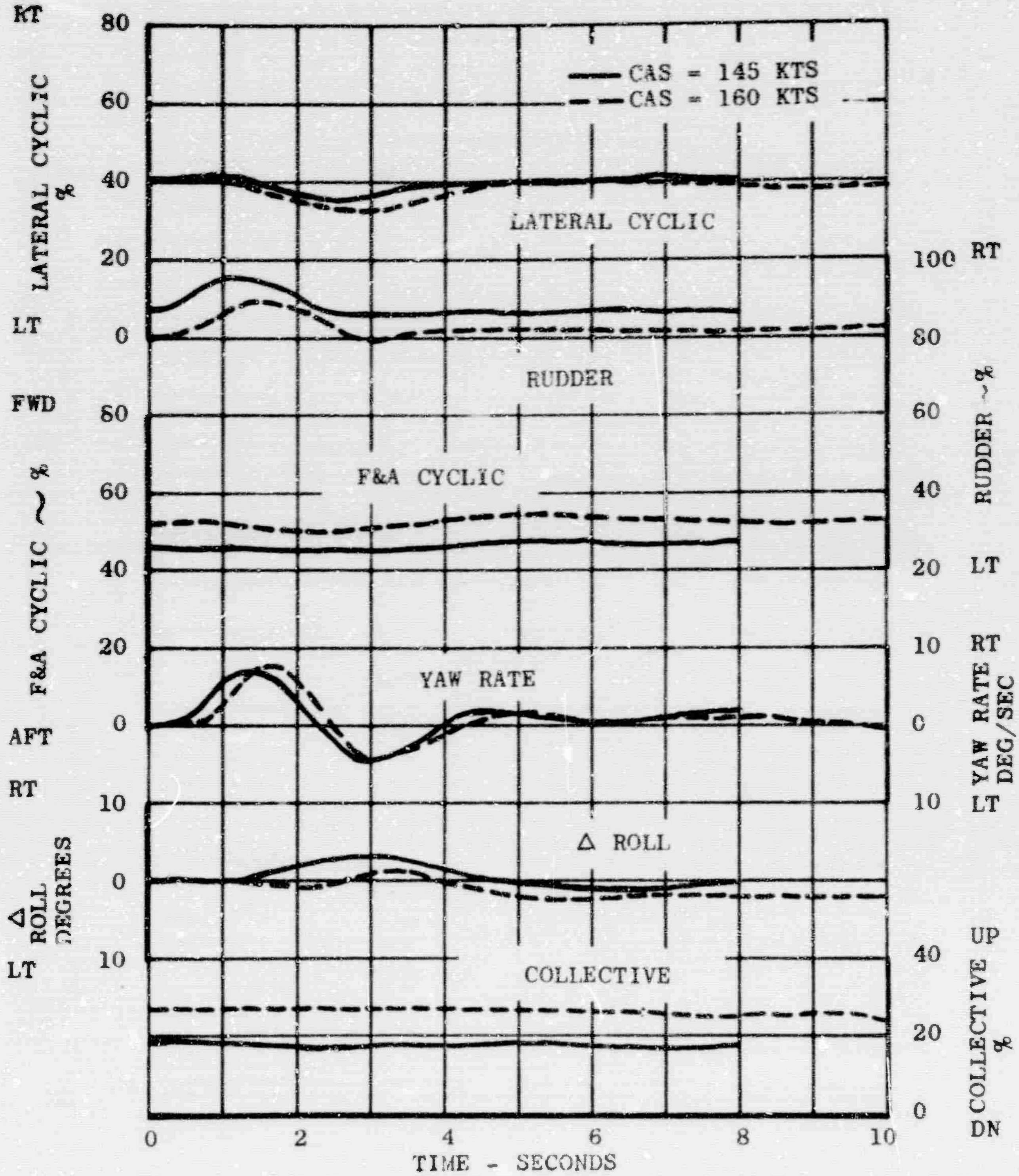

Figure 16. HELICOPTER RESPONSE TO A SIMULATED SIDE GUST FROM THE LEFT, T_J = 2400 POUNDS

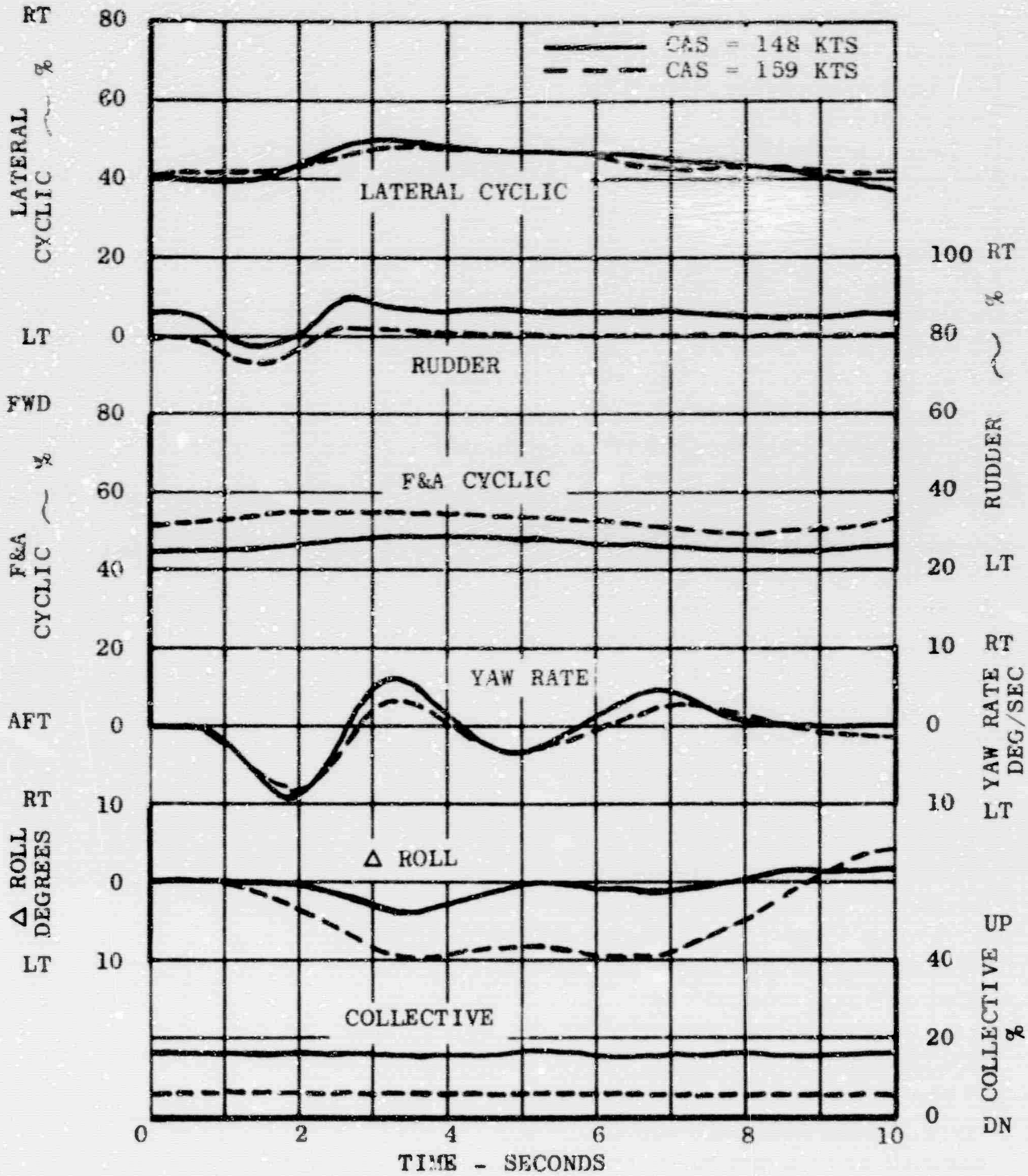

Figure 17. HELICOPTER RESPONSE TO A SIMULATED SIDE GUST FROM THE RIGHT, T_J = 2400 POUNDS